High Voltage System for the Generation of High Energy X-rays: synchronization and improvement

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Abstract

The x-ray (3 keV - 25 keV) are produced by high voltage discharge applied inside plasma source interaction chamber by focusing a laser beam. The control system is based on a high voltage power supply and an LC-inverter circuit with Thyratron, the generation of the trigger signal increasing the efficiency of the system. Analysis of the system, a possible layout with solid-state element and preliminary results of synchronization between high voltage discharge and Laser beam Nd-YAG are presented and discussed.

Introduction

The development of x-ray source based in production of plasma by Laser beam can represent a new way for modern apparatus in medical and radiobiological applications. The high energy x-ray (3 keV - 25 keV) are emitted by plasma on target driven by a control system that manages High Voltage power supply, an LC Inverter discharge and laser beam generation. Actually, in the LC-Inverter circuit the discharge is controlled by a spark gap and a trigger generator composed of Thyratron and a trigger high voltage power supply. The trigger high voltage power supply was designed with transformer and diodes rectifiers for obtaining DC voltage to send in the spark gap [1]. This configuration was resulted electrically unstable due to the electromagnetic noise and return high voltage. For these reasons, the analysis of the system is made by commercial High Voltage Power Supply, as trigger circuit, temporarily in loan. The analysis of the system involve some electrical features as well as the correct synchronization of the laser beam with the high voltage discharge. Thyratrons are obsolete as fewer and fewer vendors are selling them in response to decreased demand. An alternate solid-state device, the insulated-gate bipolar transistor (IGBT), can readily operate at the speed needed to increase the efficiency of the system. Other disadvantages of thyratrons are the increase in delay time and jitter when the tube ages. These contribute significantly to the overall phase noise of the system. A new system with IGBT to control the trigger can reduce the complexity and improve the stability and synchronization.

Materials and methods

The apparatus for the High Energy X-rays generation is composed of plasma source interaction chamber in vacuum (ranging from 10^{-3} to 10^{-5}mbar) and two main systems: a high voltage power supply, that provides a maximum voltage of 40 kV, and an LC-inverter circuit [1]. A trigger circuit supplied the LC inverter with High Voltage power supply and is sent to the Spark Gap using a Thyratron, which is used as high electrical power switch. A IRD's Photodiode (AXUV100GX -100V of polarization) is used inside chamber to measure and analyze the emission of x- rays. To increase the stability of the system, IGBT can be replaced to the Thyratron in according to the new design for combining high efficiency and fast switching. The synchronization layout of the system between trigger discharge with pulse laser beam is made by a Pulse Generator by Quantum Components as described in figure 1.

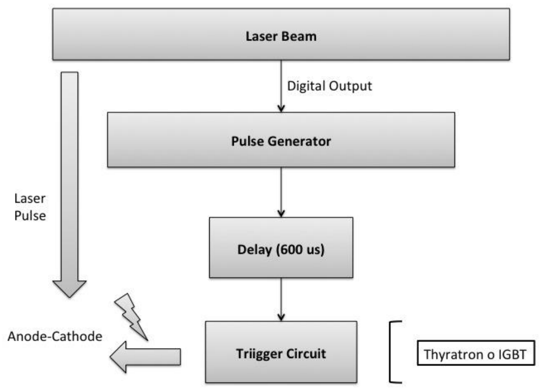

Figure 1: Synchronization Layout. Digital output is generated simultaneously with laser beam and is sent to the Pulse Generator as trigger for obtaining a new signal delayed about 600 us which controls the trigger circuit.

Results

The results of p-spice model in [1], let us to test the system using a High Voltage Power Supply at 15 kV. X- rays measured by photodetector (PD) with an aluminum foils of 15.8 µm thickness (figure 2). In figure 2 is show the high current and voltage signals where is noted as the LC Inverter doubles the input voltage before of x-ray production (about 300 ns). After that, the behaviour of the circuit is a typical LC. The synchronization of the system is made considering that the x-ray signal is started 13 us after the trigger signal. As indicated in figure 1 the total delay to set in the pulse generator should be around 600 us; actually the time difference is around 2 us as shown in figure 3 where is indicated external diode signal used to measure the intensity of laser beam (plasma source) and the trigger signal sent to the Thyratron to active the discharge.

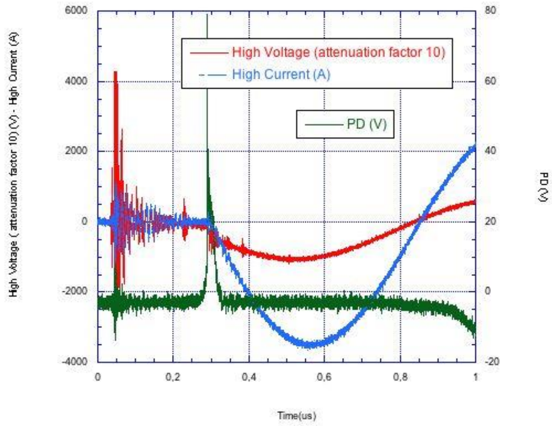

Figure 2: Experimental Signals in vacuum of 10^{-3} mbar with 15kV of Power supply: In blue line, High Current Signal, in red line the High Voltage with attenuation factor of 10 and in green line, the x-ray emission.

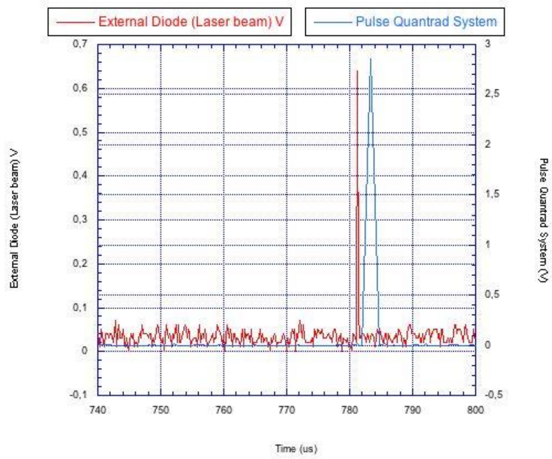

Figure 3: Preeliminary set-up of the synchronization: in red line, external diode to measure the laser beam (plasma source), in blue linee the trigger sent to the Thyratron. Actually, the time difference is around 2 us.

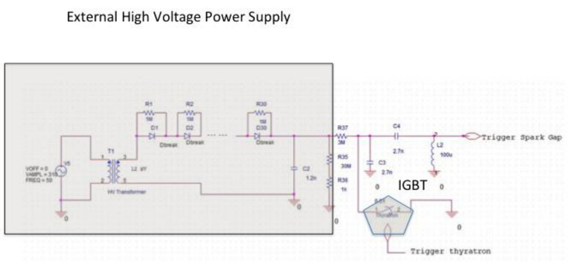

Figure 4: General New Layout of Trigger circuit

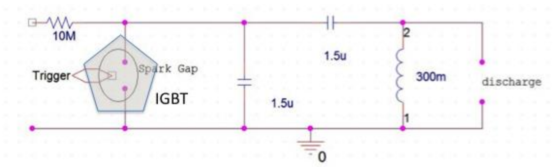

Figure 5: General New Layout of LC Inverter

Conclusions and Discussion

The characterization of the system lead us new features to design a possible new system using IGBT. IGBT is a promising power device for high power applications thanks to the robust characteristics offered by the field-stop technology. The PSPICE IGBT model is described by an equivalent circuit in [2] and [3]. Five dc current components and six charge components describe the different fundamental physical effects of the IGBT. The idea of new design is replaced the Thyratron and Spark Gap as High Power Switching with solid-state element (Gray block in Figure 4 and 5). Moreover, the synchronization of laser beam and discharge using Pulse Generator of Quantum Components is very useful to synchronize all signals (figure 3). The synchronization can be improvement using a photodetector for detecting the light of discharge and synchronazing with laser beam and x-ray emission. This new photodetector will be placed close to the anode-cathode of interaction chamber or spark gap to measure the duration of the discharge light.

Then, we will examine x-rays emission by changing the distance from anode and cathode and power density of the laser. The design of IGBT circuit must to be done in consideration the values of the high current of the system. A model circuit for high voltage levels will be implemented and designed in the system (figure 6).

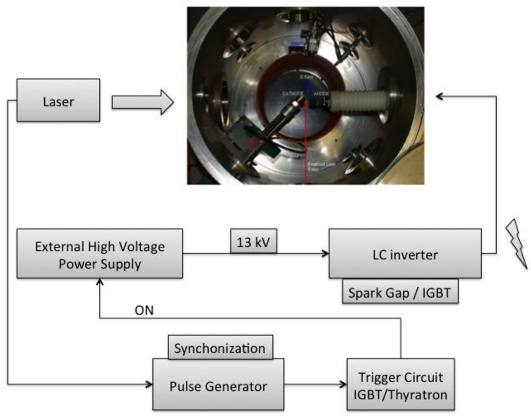

Figure 6: New system Layout

References

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